

# Short Course on Experimental Dynamic Substructuring

## Module #9: Closing Remarks



THE UNIVERSITY  
of  
**WISCONSIN**  
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**Short Course Notes For:**

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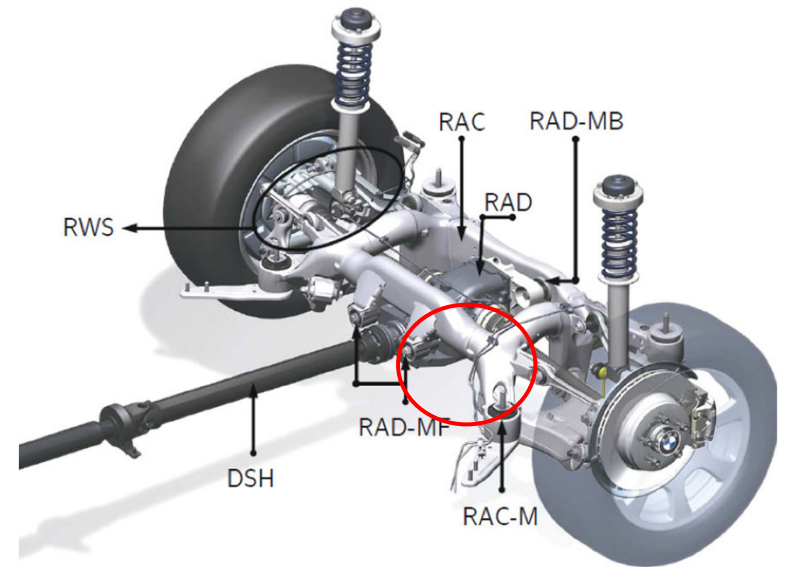
# Other Topics of Interest

## ■ Transfer Path Analysis

- ❑ Used to characterize vibration sources when the forces causing the motion are unknown.
- ❑ Closely related to the theory covered here!
- ❑ See references for a starting point.

## ■ Nonlinear Substructuring of weakly nonlinear systems for structures with joints

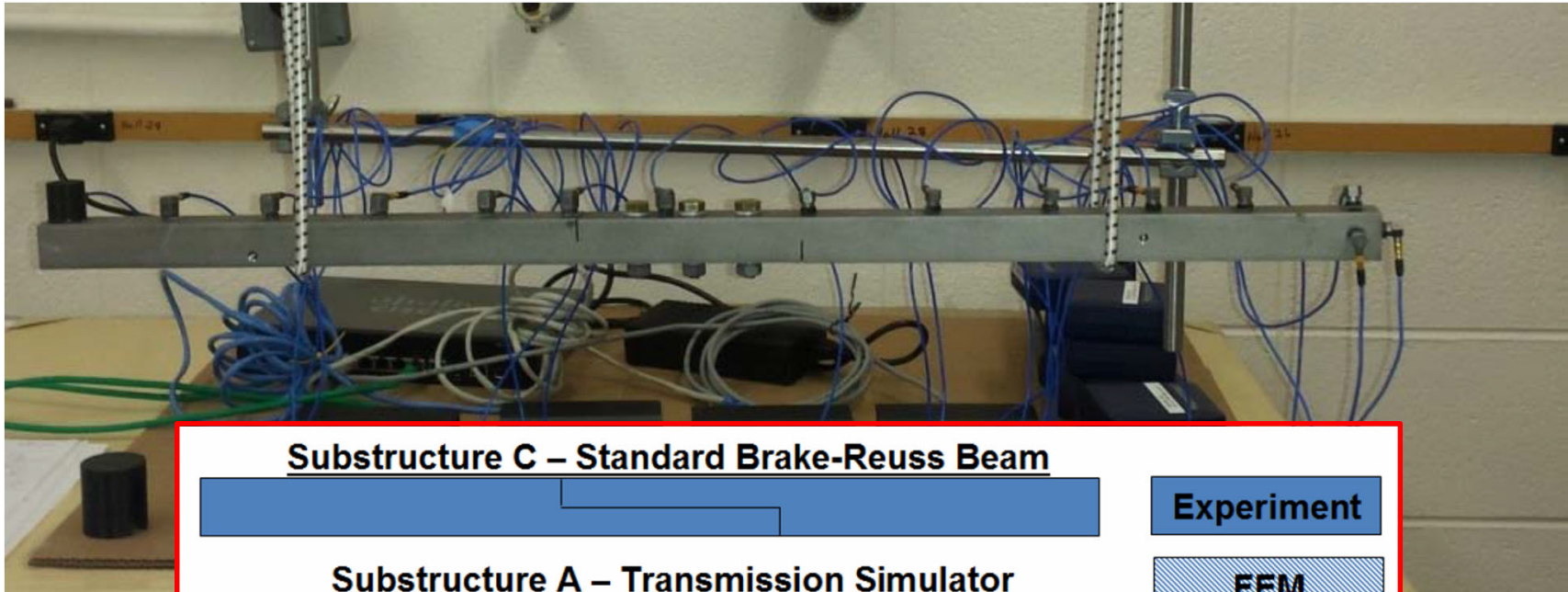
- ❑ [1] D. R. Roettgen and M. S. Allen, "Experimental Dynamic Substructuring of a Catalytic Converter System using the Transmission Simulator Method," presented at the 33rd International Modal Analysis Conference (IMAC XXXIII), 2015.
- ❑ [2] M. S. Allen, D. R. Roettgen, D. C. Kammer, and R. L. Mayes, "Experimental Modal Substructuring with Nonlinear Modal Iwan Models to Capture Nonlinear Subcomponent Damping," presented at the 34th International Modal Analysis Conference (IMAC XXXIV), 2016.



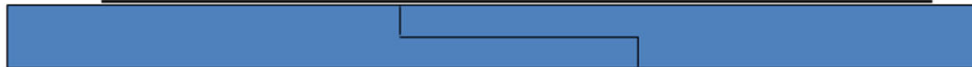
# References and bibliography for TPA *(non exhaustive!)*

- 1 D. de Klerk. *Dynamic Response Characterization of Complex Systems through Operational Identification and Dynamic Substructuring: An application to gear noise propagation in the automotive industry*. PhD thesis, Delft University of Technology, Delft, The Netherlands, March 2009.
- 2 G. van Schothorst, A. Boogaard, T. van der Poel, and D. Rixen. Analysis of ground vibration transmission in high precision equipment by frequency based substructuring. In P. S. et al., editor, *International Conference on Noise and Vibration Engineering, ISMA*, number 915, KUL, Leuven, Belgium, 17-19 September 2012.
- 3 D. J. Rixen, A. Boogaard, M. V. van der Seijs, G. van Schothorst, and T. van der Poel. Source description in vibration transmission between substructures: blocked forces and free velocities. *Journal of Sound and vibration*, (submitted), 2014.
- 4 A. Moorhouse, A. Elliott, T. Evans, In situ measurement of the blocked force of structure-borne sound sources, *Journal of Sound and Vibration* 325 (4–5) (2009) 679 – 685. doi:<http://dx.doi.org/10.1016/j.jsv.2009.04.035>. URL <http://www.sciencedirect.com/science/article/pii/S0022460X09003794>

# Experimental Substructuring with Nonlinear Joints

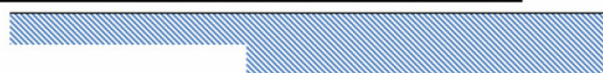


**Substructure C – Standard Brake-Reuss Beam**



**Experiment**

**Substructure A – Transmission Simulator**



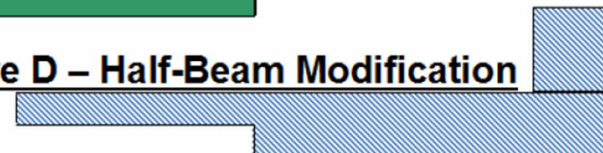
**FEM**

**Substructure B – Half-Beam Model ( $B=C-A$ )**

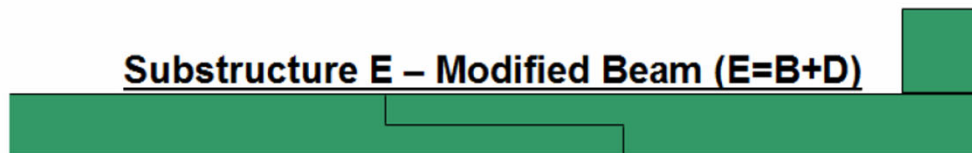


**Prediction**

**Substructure D – Half-Beam Modification**



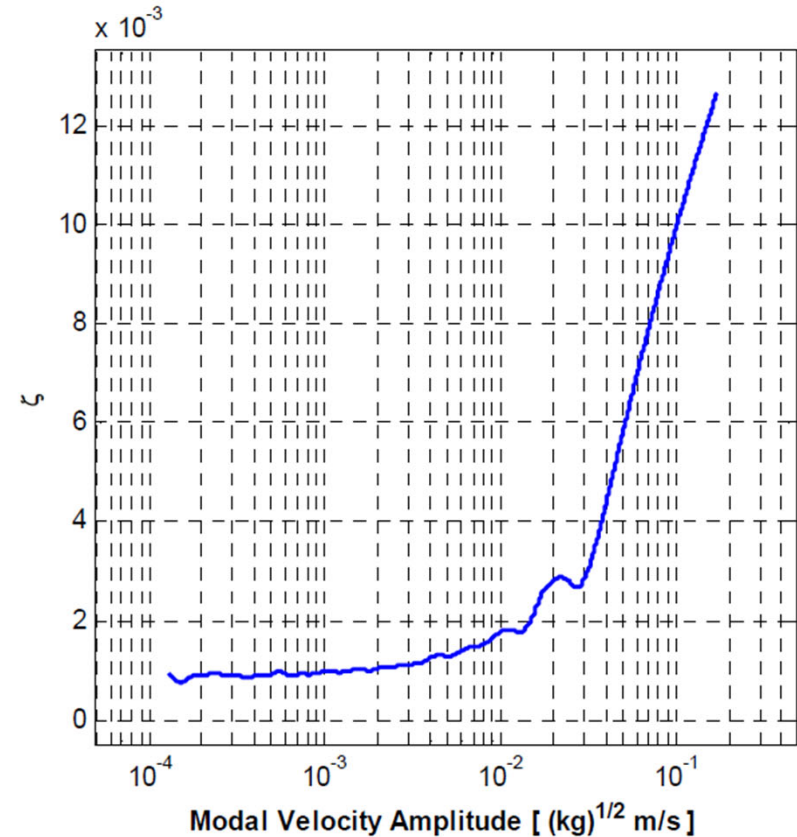
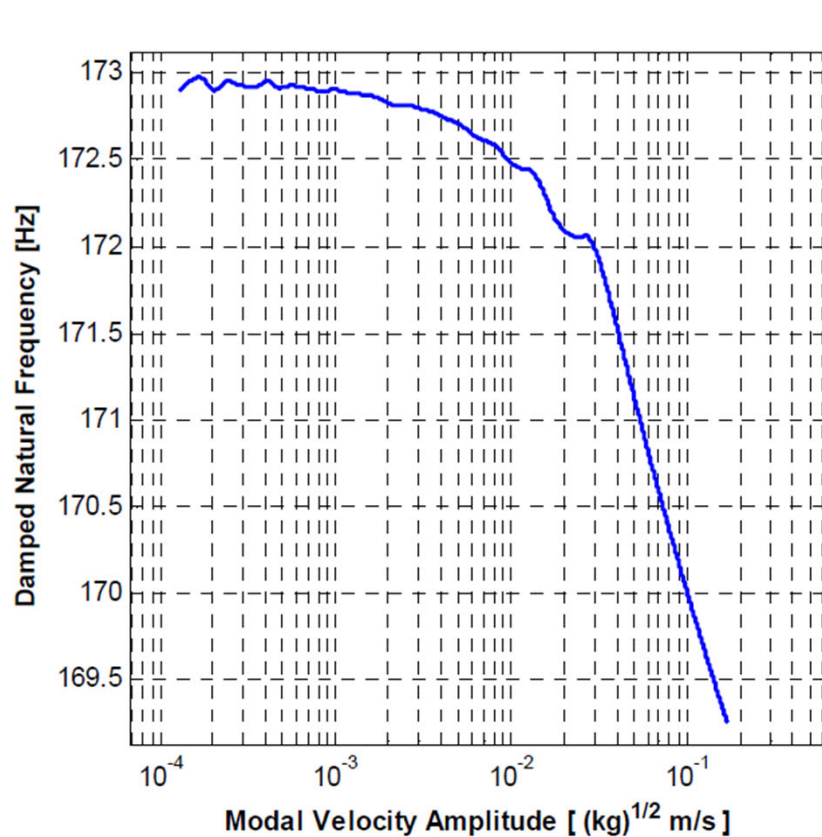
**Substructure E – Modified Beam ( $E=B+D$ )**





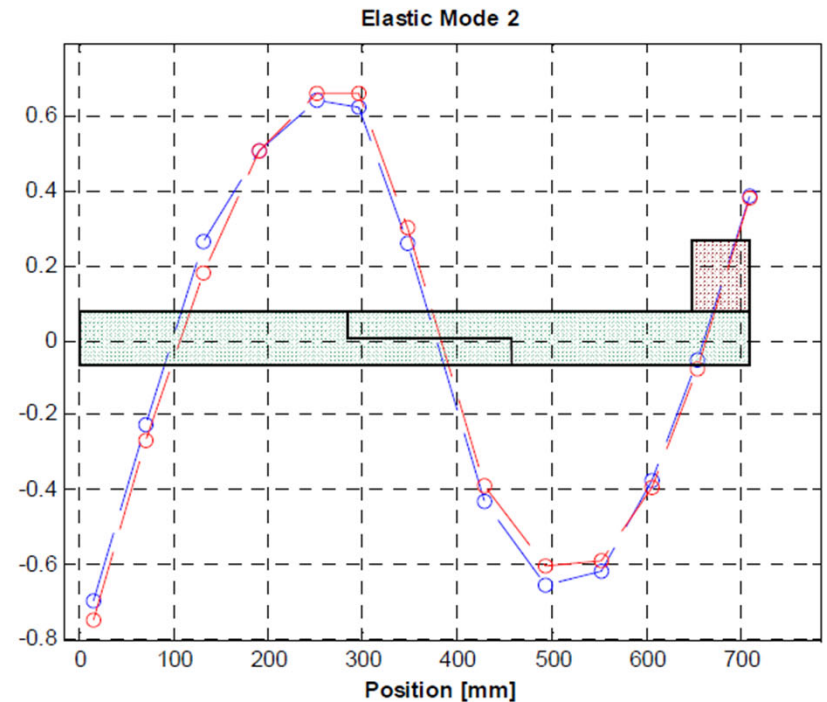
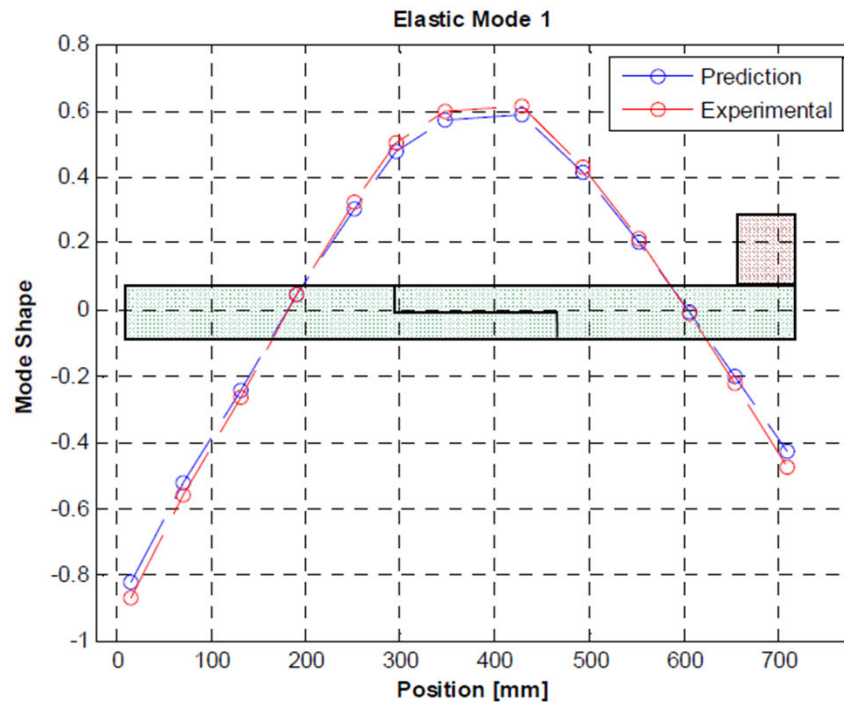
# Measured Nonlinear Modes of Original BRB

**Substructure C – Standard Brake-Reuss Beam**



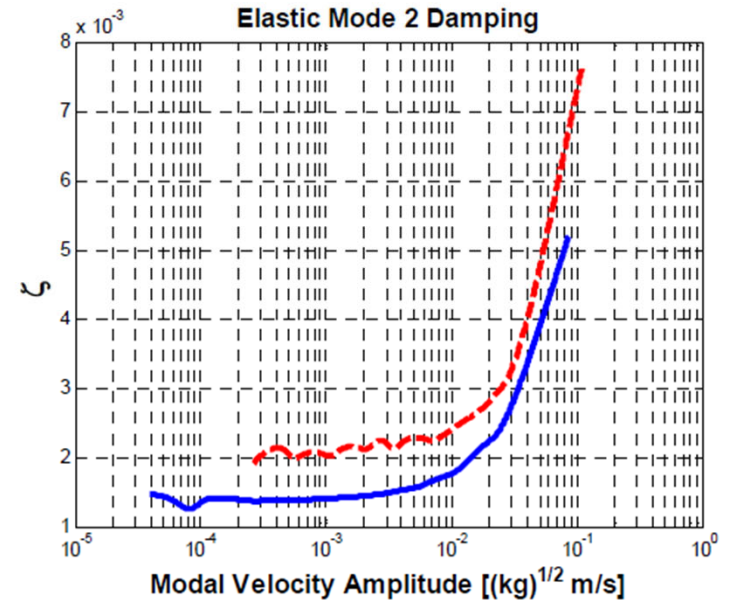
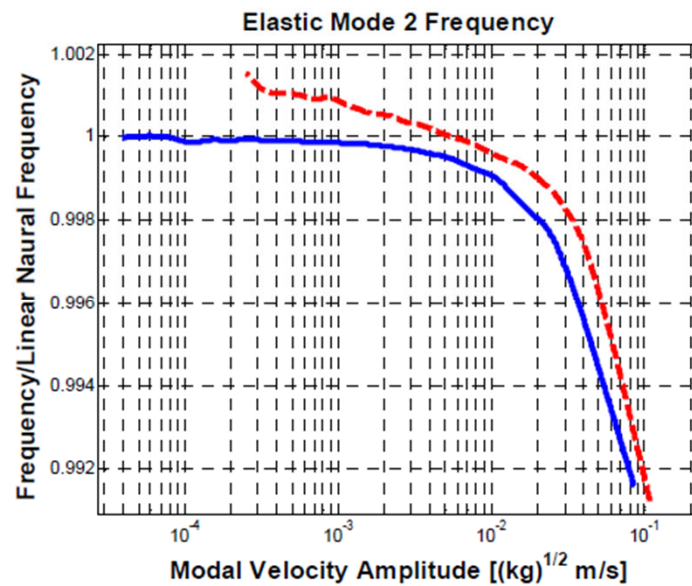
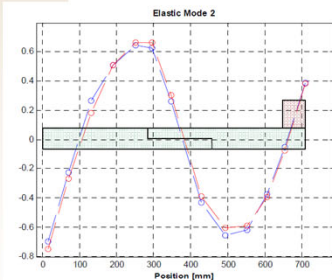
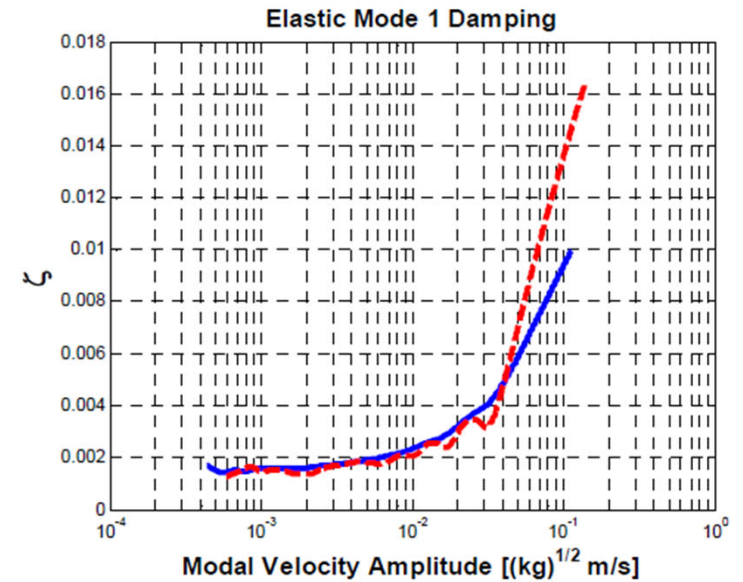
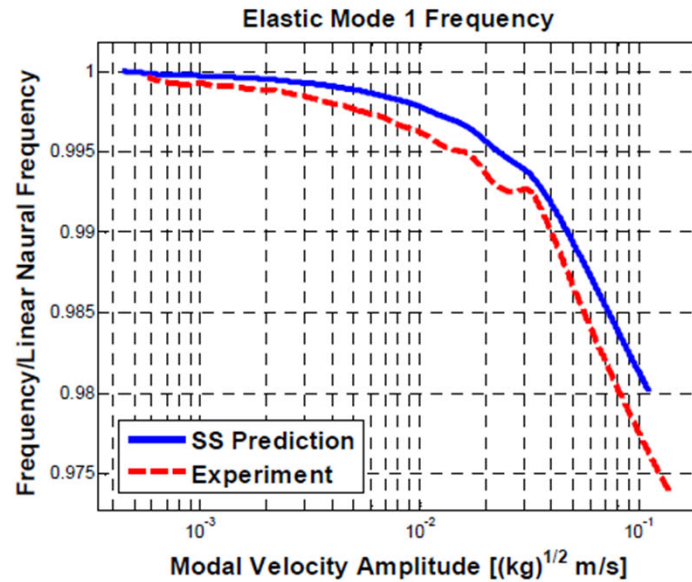
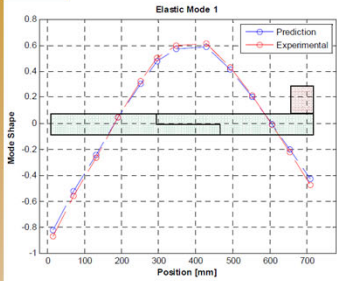
- Created a modal model for the Brake-Reuss Beam by measuring the frequency and damping as a function of amplitude for the lower modes.

# Linear Modes of the New Assembly



- Removed the right half of the beam and replaced with a beam with a large mass attached.

# Nonlinearity in Modes 1 and 2 of Assembly



## Concluding Remarks

- While many of the classical concepts involved in substructuring have been around for decades, experimental-analytical substructuring is an area ripe for discovery!
  - ❑ Better experimental methods are still needed
  - ❑ Extensions to weakly and strongly nonlinear systems
  - ❑ Transfer Path Analysis (TPA) and force reconstruction
  - ❑ etc...
- We hope you have enjoyed the course and welcome any feedback that you may have!